André-Marie Ampère

The first investigator to quantify the magnetic effects of electric current, Ampère was also a pioneer in the philosophy of science. His philosophy shaped his method of scientific discovery

by L. Pearce Williams

When my freshmen students ask me who André-Marie Ampère was, I often reply, "You probably know him better as Amps; he comes in two sizes, 15 and 35." In fact, Ampère is best known as the founder of the science of electrodynamics. In the early 19th century he carried out the first systematic investigations of the magnetic fields produced by electric currents, discovered and quantified the forces that act between current-carrying wires, and was the first investigator to propose that the magnetism observed in permanent magnets is caused by tiny electric currents circulating within the molecules of magnetic material. His achievements are commemorated in the name of the international unit of electric current: the ampere, or amp—the unit in which electric fuses, such as the common 15- and 35-amp fuses, are sized.

Ampère is less well known for his achievements as a philosopher of science, although they were in some ways just as significant. He was the first major scientist to adapt the views of the German philosopher Immanuel Kant to provide a philosophical foundation for the study of physics and chemistry. Ampère took Kant's theory of knowledge—his theory of what human beings can know and how they can come to know it—as a starting point in developing a practical method of scientific discovery. Kantian philosophy eventually came to pervade the physical sciences, particularly in the late 19th and early 20th centuries, and Ampère's method of discovery, which guided his investigations of electrodynamics, survives today in modified form as one of the most commonly accepted scientific methodologies.

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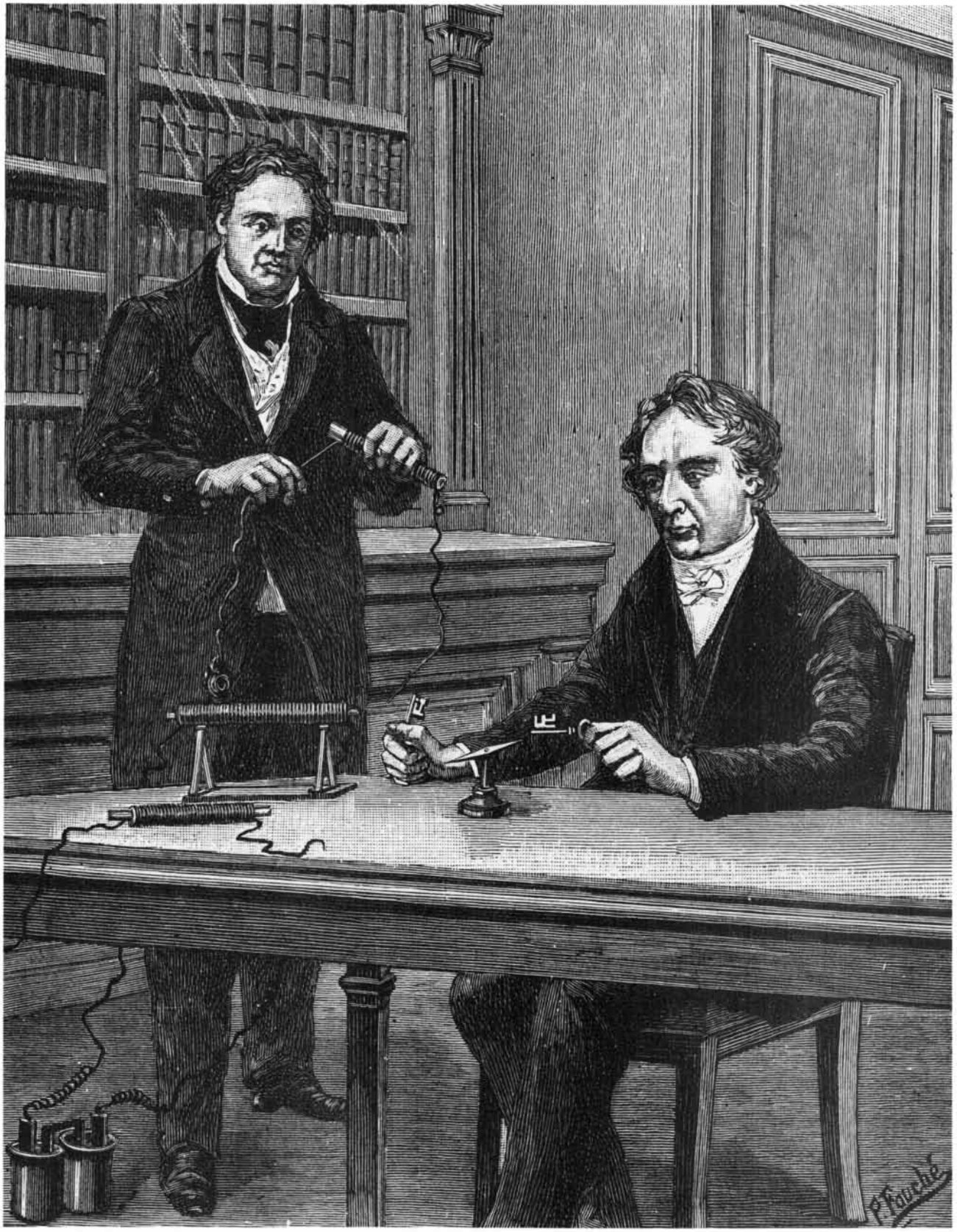
Born in 1775, Ampère grew up in the village of Poleymieux, outside Lyons. As a youth he educated himself, avidly reading books from his father's library and volumes brought from Lyons. He devoured Denis Diderot's newly completed *Encyclopédie,* committing entire articles to his photographic memory. He was particularly interested in mathematics; he worked his way through the treatises of the Swiss mathematician Leonhard Euler on advanced algebra, probability theory and the calculus, and in his late teens he mastered Joseph-Louis Lagrange's groundbreaking book on analytical mechanics. His interests outside mathematics were literally encyclopedic. Ampère studied Georges de Buffon's works on natural history, learned Greek, Latin and Italian, tried to develop a universal language that would be based on the most up-to-date principles of linguistics, immersed himself in French literature, wrote poetry, studied botany and developed ways to systematize his own observations of the natural world. This broad range of interests never left him.

For his first 18 years, Ampère, as the only son in a family of comfortable means, led a nearly idyllic existence, wandering wherever he liked—physically and intellectually—in a secure, stable world. In 1793, however, began a series of personal tragedies that punctuated the rest of his life. In 1793 his father was guillotined as a counterrevolutionary. In 1803 his beloved wife of four years (and mother of his son, Jean-Jacques) died, and four years later he entered into a disastrous second marriage that ended in divorce, leaving him with a young daughter. A few years of relative calm were shattered in 1819, when his son left all prospects behind to join the retinue of Mme Récamier, the great beauty of the Napoleonic era, who collected male admirers and resolutely kept them at arm's length. Jean-Jacques attended her for the next 20 years, ignoring his father's pleas to return home and make something of himself. In 1827 Ampère married his daughter to a former officer of Napoleon's army, only to find later that the man was both an alcoholic and insane.

Throughout his life Ampère suffered from a steady deterioration of his health, which increasingly impeded his scientific efforts. He also suffered from financial insecurity for most of his life and had to take a variety of low-paying jobs, most of which involved teaching mathematics at one level or another.

Ampère's development as a scientist was hindered not only by these personal circumstances but also by the breadth of his own intellectual activity. In a recently discovered collection of letters, written when he was 20 years old, he jumps from theoretical mechanics to the construction of practical machinery, to the theory of kite flying, to artificial languages, to music, to astronomy, to botany, to systems of classification. He was never able to focus narrowly on a given area and bring his full genius to bear on it. While he was feverishly developing his electrodynamics he continued to speculate on problems of metaphysics and philosophy. He never saw any contradiction in all of this, for he was convinced that a basic unity underlies all knowledge. As we shall see, his last



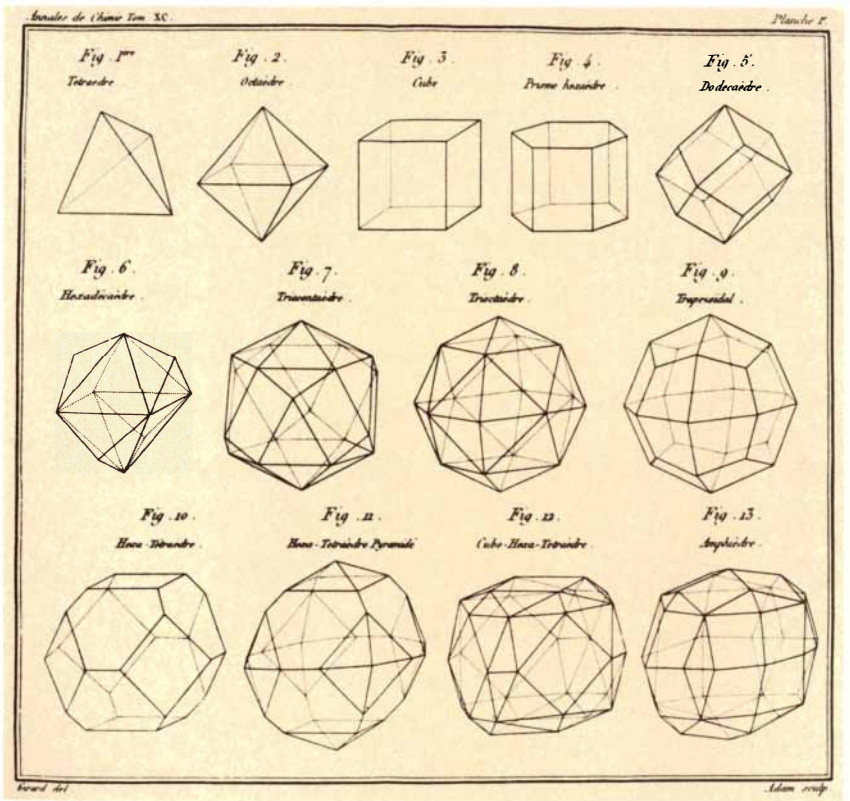
ANDRÉ-MARIE AMPÈRE (*left*) and his friend François Arago examine the magnetic effects of electric currents in an imaginative (and somewhat inaccurate) late 19th-century reconstruction of their collaboration. Ampère, who was a founder of electrodynamics (the study of electric currents), adapted philosophical ideas to provide a methodological framework for scientific investigation. Arago was the investigator who told Ampère and his colleagues in the French Academy of Sciences of the Danish physicist Hans Christian Oersted's discovery that an electric current could deflect a nearby compass needle.

major work was an attempt to demonstrate that point.

When Ampère first began his scientific work, French philosophy was dominated by a school whose members had been contemptuously dubbed Idéologues by Napoleon. The Idéologues professed to have determined the complete rules for proper scientific procedure. According to their beliefs, the human mind is a passive receptor of sensory impressions. On the basis of these impressions the mind creates a series of pictures (which include sensations of smell, sound, taste and touch in addition to sight) that represent the outside world. The mind can recall pictures and compare them, in order to determine their differences and to ascertain how the succession of images changes over time. Any observed regularities can then serve as the basis for scientific laws. Yet there is no way to tell whether there really is an outside world. The only known reality lies in the pictures.

In this world view there is no causation, merely a succession of images. It is thus impossible, in one sense, to explain phenomena—to speak of the physical forces by which a certain cause brings about a particular effect. Hence there can be no scientific theories, in one modern sense of the word. On the one hand, science becomes taxonomic: the scientist arranges similar sensations in properly organized groups. On the other, it becomes positivistic: the scientist expresses observed regularities in mathematically rigorous laws. A good example of the first kind of science is Antoine Lavoisier's system of chemistry, which was based on exact description, precise nomenclature and proper classification of chemical elements and compounds. The second kind of science was typified by Jean-Baptiste Fourier's studies of heat, in which Fourier ignored the causes of heat, concentrating instead on determining the mathematical laws of thermal propagation. Such a philosophical framework is adequate for many kinds of scientific study, but it essentially rules out such fields as microphysics, which relies on theoretically posited entities that cannot be observed directly, such as atoms and molecules.

Ampère's early scientific work was not limited by this framework; he began his career as a mathematician, and mathematics need not refer to an external physical reality. Ampère's first published paper, written in 1802 to gain him the reputation necessary to be named professor at the Napoleonic lycée in Lyons, was on the mathematical theory of gambling. In this small treatise Ampère showed that a gambler who has a finite amount of money but faces either a single opponent with infinite financial resources or a large number of opponents with finite resources will necessarily lose all within a finite amount of time. Ampère also wrote papers on theoretical mechanics, and his most extensive mathematical work—written to gain election to the French Academy of Sciences—was a treatise on partial differential equations. A number of other mathematical papers complete this phase of his career. Had his efforts been confined to mathematics, he would now be known, if at all, as a competent and sometimes innovative mathematician who was overshadowed by his contemporaries Laplace, Poisson, Cauchy and Fourier.

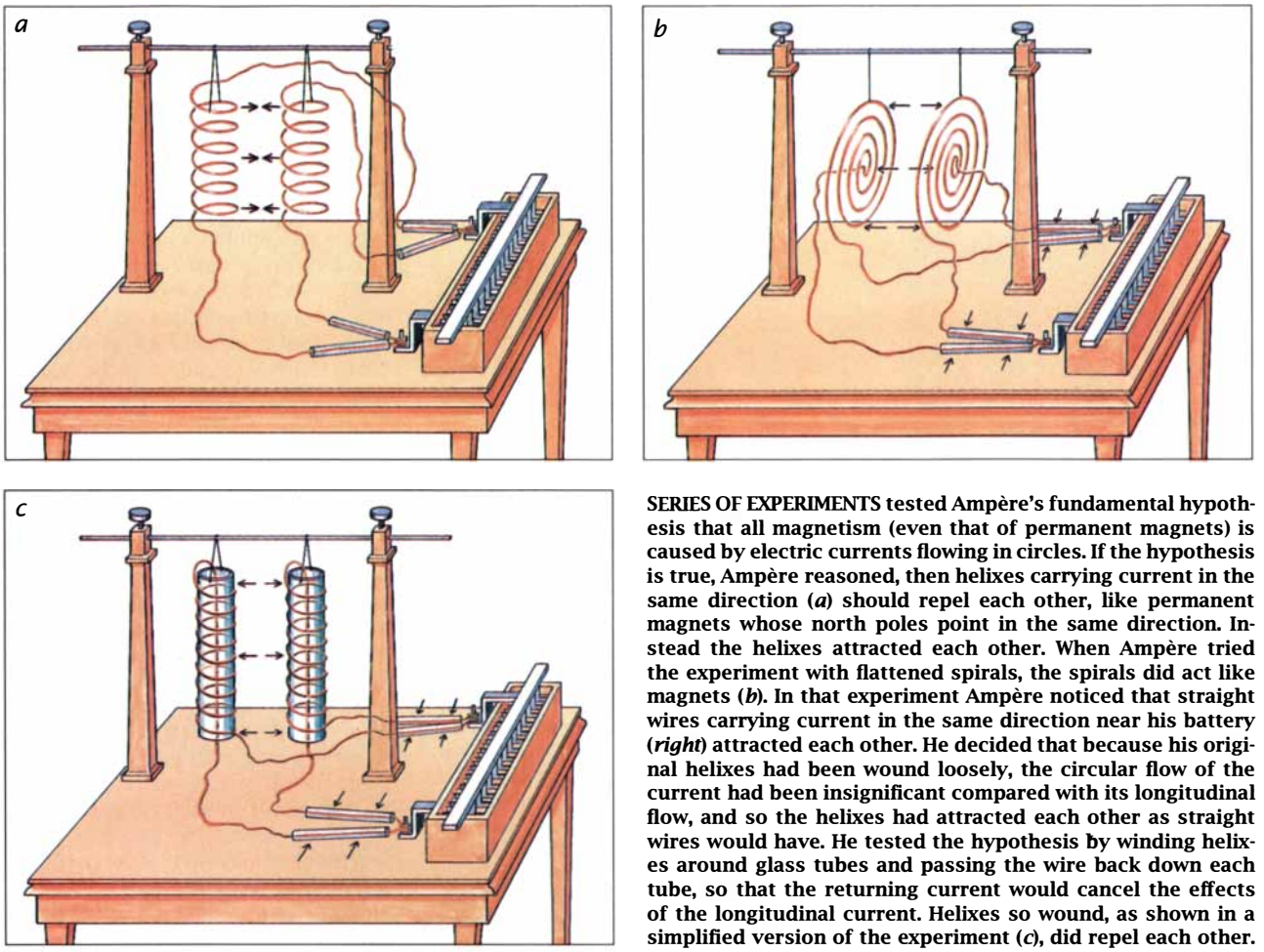


POLYHEDRAL MOLECULES formed the conceptual basis of Ampère's early work in theoretical chemistry. Motivated by Immanuel Kant's assertion that true sciences should be based on mathematical principles, Ampère attempted to explain chemistry in terms of geometry. In Ampère's scheme the most fundamental molecules were made of points arranged as the vertexes of the regular or nearly regular solids in the top row of this chart (which is from a paper by Ampère in *Annales de Chimie*). Reactions between these molecules could occur only if they resulted in solids with a degree of regularity and symmetry, such as those in the other two rows.

One reason for Ampère's failure to break new ground in mathematics was that by 1805 he was bored with the subject. He had found two new passions: metaphysics and chemistry.

Ampère's fascination with metaphysics sprang from his introduction to the Idéologues in 1804, when he moved from Lyons to Paris after the death of his first wife. Ampère was one of a small group of philosophers who gathered in the suburban village of Auteuil to discuss the work of the Abbé de Condillac, the founder of the Idéologue school. He was soon repelled by the views of the Idéologues because they ruled out the existence of God and the immortal soul, and he left the group to search for an alternative. He found inspiration for his own philosophy in the writings of Kant.

Kant divided the world into two domains: the domain of phenomena and the domain of noumena. Phenomena are events as perceived by the human mind—they are sensations. Noumena are the causes of phenomena—they are the so-called things-in-themselves, the objects that really exist. Human beings can never know the noumena



SERIES OF EXPERIMENTS tested Ampère's fundamental hypothesis that all magnetism (even that of permanent magnets) is caused by electric currents flowing in circles. If the hypothesis is true, Ampère reasoned, then helixes carrying current in the same direction (*a*) should repel each other, like permanent magnets whose north poles point in the same direction. Instead the helixes attracted each other. When Ampère tried the experiment with flattened spirals, the spirals did act like magnets (*b*). In that experiment Ampère noticed that straight wires carrying current in the same direction near his battery (*right*) attracted each other. He decided that because his original helixes had been wound loosely, the circular flow of the current had been insignificant compared with its longitudinal flow, and so the helixes had attracted each other as straight wires would have. He tested the hypothesis by winding helixes around glass tubes and passing the wire back down each tube, so that the returning current would cancel the effects of the longitudinal current. Helixes so wound, as shown in a simplified version of the experiment (*c*), did repel each other.

directly: noumena are the sources of the signals that act on our senses, and we can perceive only the signals, not the sources. According to Kant, then, we cannot ever really know anything definite about the noumena.

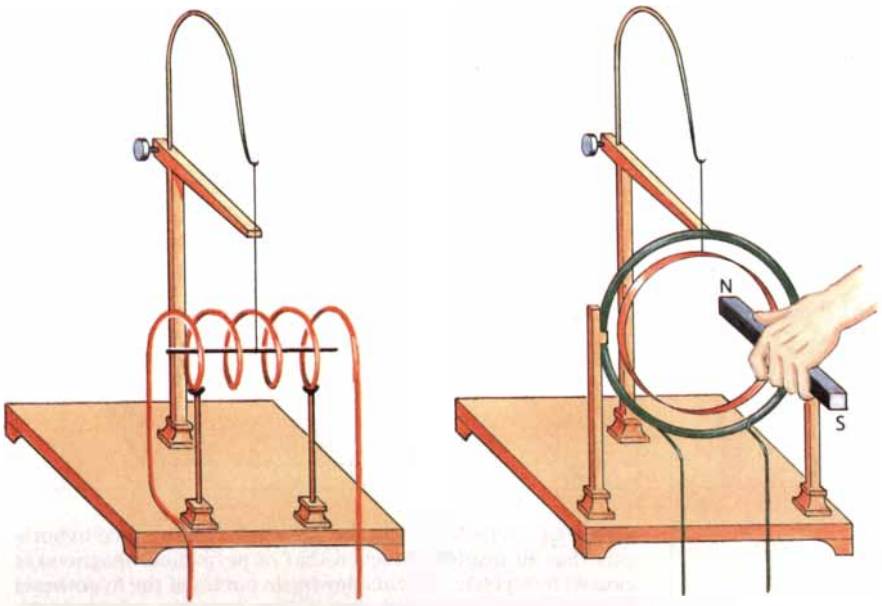
It was on this point that Ampère broke from Kant. Ampère noted that there are often relations—*rapports*, to use his word—between phenomena. Those *rapports*, he believed, must be analogous to *rapports* between the noumena underlying those phenomena. Hence it should be possible to learn about the interactions between unobservable noumena by studying phenomenal *rapports*.

This philosophical assertion was the foundation on which Ampère built his method of scientific discovery. He explained his method in a letter written in 1810 to his old friend Marie-François Pierre Maine de Biran. In Ampère's method the scientist accounts for phenomena by hypothesizing the existence of certain noumenal entities. Then he engages in a process of deduction: Accepting the existence of the theoretical entities, what new experimental results—phenomena—can be expected? The deduction is then tested by experiment. The theoretical entities can be assumed to exist as long as they give a testable account of phenomena. The probability that the theory is true increases as its ability to withstand experimental attack is demonstrated. Ampère's method is known today as the hypothetico-deductive approach, and it is viewed by many as the proper way to conduct scientific research.

A good example of the method in action is Ampère's analysis of Joseph-Louis Gay-Lussac's law of combining volumes. According to this phenomenal law, when integral volumes of gases are combined in a reaction, they must produce an integral volume of product; for example, when two liters of hydrogen are combined with one liter of oxygen, the product is precisely two liters of water vapor. For the Idéologues, that was as far as one could go; one could not say *why* the law is true. Ampère was determined to go further. In 1814 he argued, in one of the first modern papers on theoretical chemistry, that one could account for the phenomena only by assuming that equal volumes of different gases at the same temperature and pressure must contain the same number of molecules. The existence of molecules—unobservable noumena—is the basis of Ampère's explanation of the phenomena described by Gay-Lussac.

Soon after devising his method, Ampère applied it to develop a brilliant theoretical framework for chemistry. Kant had insisted that sciences must be founded on a priori mathematical principles—principles that he believed are inherent in the structure of the human mind and are not based on observation. Following Kant's teaching, Ampère tried to deduce the laws of chemical affinity (the laws that determine which chemical reactions are possible) by assuming the existence of hypothetical molecules that were geometric in nature.

Ampère assumed that each molecule was composed of pointlike atoms



NATURE OF CURRENTS underlying magnetism was explored in a pair of experiments carried out separately by Arago and Ampère. In the first experiment (*left*) Arago wound a helix of copper wire, suspended an iron needle in the center and ran a current through the helix. The needle became magnetized. Ampère thought to test whether the circular currents responsible for permanent magnetism flow around every particle of magnetic material or around the axis of the magnet as a whole. In his experiment (*right*) he wound a coil of insulated copper wire (*green*) and suspended within it a ring made of copper ribbon. If the current in the coil had magnetized the needle by making currents flow around its central axis, Ampère thought, it should also magnetize the copper ring, because currents could circulate around its axis. He ran a current through the coil and held a bar magnet near the ring to see if it had become a "permanent" magnet. It had not, convincing Ampère that the currents in permanent magnets circulate around individual particles and not the magnetic axis. (The experiment—but not the conclusion—is flawed from a modern perspective.)

arranged in space as the vertexes of a simple geometric solid, such as a tetrahedron, an octahedron or a cube. The only chemical combinations that could occur were those that produced geometric solids having a certain degree of three-dimensional symmetry and regularity. In Ampère's theoretical framework the puzzling arbitrariness of chemical activity could be reduced to mathematical certainty: chemistry could be based on geometry, which Kant believed was the purest form of mathematics. I should note that neither of Ampère's chemical papers attracted much support from chemists, who were hostile to both his speculations and his mathematics.

Ampère's accomplishments by the year 1819, when he was 44, would probably rate only a footnote in the history of physics. Unlike his contemporaries Augustin Fresnel (Ampère's close friend and a creator of the undulatory theory of light) and Sadi Carnot (a founder of thermodynamics), who died at the ages of 39 and 36 respectively, Ampère did his greatest scientific work in middle age, after he had despaired of ever making a serious mark.

Ampère's first experiments in electrodynamics involved the voltaic pile, which had been invented by Alessandro Volta in 1800. A voltaic pile is an electrochemical cell, much like a modern automobile battery. If the poles of a voltaic pile are connected by a wire, a current will flow along the wire while chemical reactions inside the cell act to preserve the voltage difference between the poles.

Continuous electric current was a new phenomenon in the early 19th century, and early theories of current relied heavily on theories of static electricity. Few people expected current to have any magnetic effects, because Charles de Coulomb had shown in the 1780's that the forces associated with static electricity are distinct from magnetism. Only a few German and German-influenced "nature philosophers," who believed in the unity of all forces, sought a relationship between electricity and magnetism.

One of these philosophers was Hans Christian Oersted of Denmark. In 1807 and 1812 he published works insisting, on philosophical grounds, that electricity and magnetism must be related. In the winter and spring of 1820 he finally detected a relationship by holding a compass needle near a long wire; when current flowed in the wire, the needle was deflected. Oersted's finding was published in all the leading scientific journals of the day.

The news was brought to Paris by François Arago, a friend of Ampère's, who had witnessed the effect during a visit to Geneva. Members of the Academy of Sciences were skeptical of Arago's report, and they were convinced only by his actual demonstration of the effect on September 11 of that year. Ampère was present at the demonstration, and he went home to investigate the effect for himself. He immediately realized that Oersted had not fully understood the experiment—he had not taken account of terrestrial magnetism. The amount by which his compass needle had been deflected depended on the angle between the current-carrying wire and the earth's magnetic field.

Ampère set out immediately to find the true effect of electric current on a compass needle by devising an arrangement of freely rotating magnets that neutralized the earth's magnetic field in a small region. To his great satisfaction he found that the compass needle now always aligned itself at right angles to the current-carrying wire. He then realized that a compass needle could be used as part of an instrument to detect an electric current. With his new instrument, which he called a galvanometer, he mapped the current throughout a circuit made up of a wire and a voltaic pile.

Until then it had been assumed that the mechanisms operating within a voltaic pile were distinct from the current flowing along a wire connecting the pile's two poles. Ampère found to his surprise that the current flowing through the voltaic pile was the same as the current in the rest of the circuit. What would happen, he wondered, if he constructed a circular pile—a pile bent into a ring so that the positive pole touched the negative pole? It appears from indirect evidence that he built such a pile during the same fertile September of 1820 and found that it created a symmetrical magnetic field. At this point Ampère's mind leaped to the hypothesis that he would defend for the rest of his life: Magnetism is no more than electric currents moving in circles. This was as far as he had got by September 18,

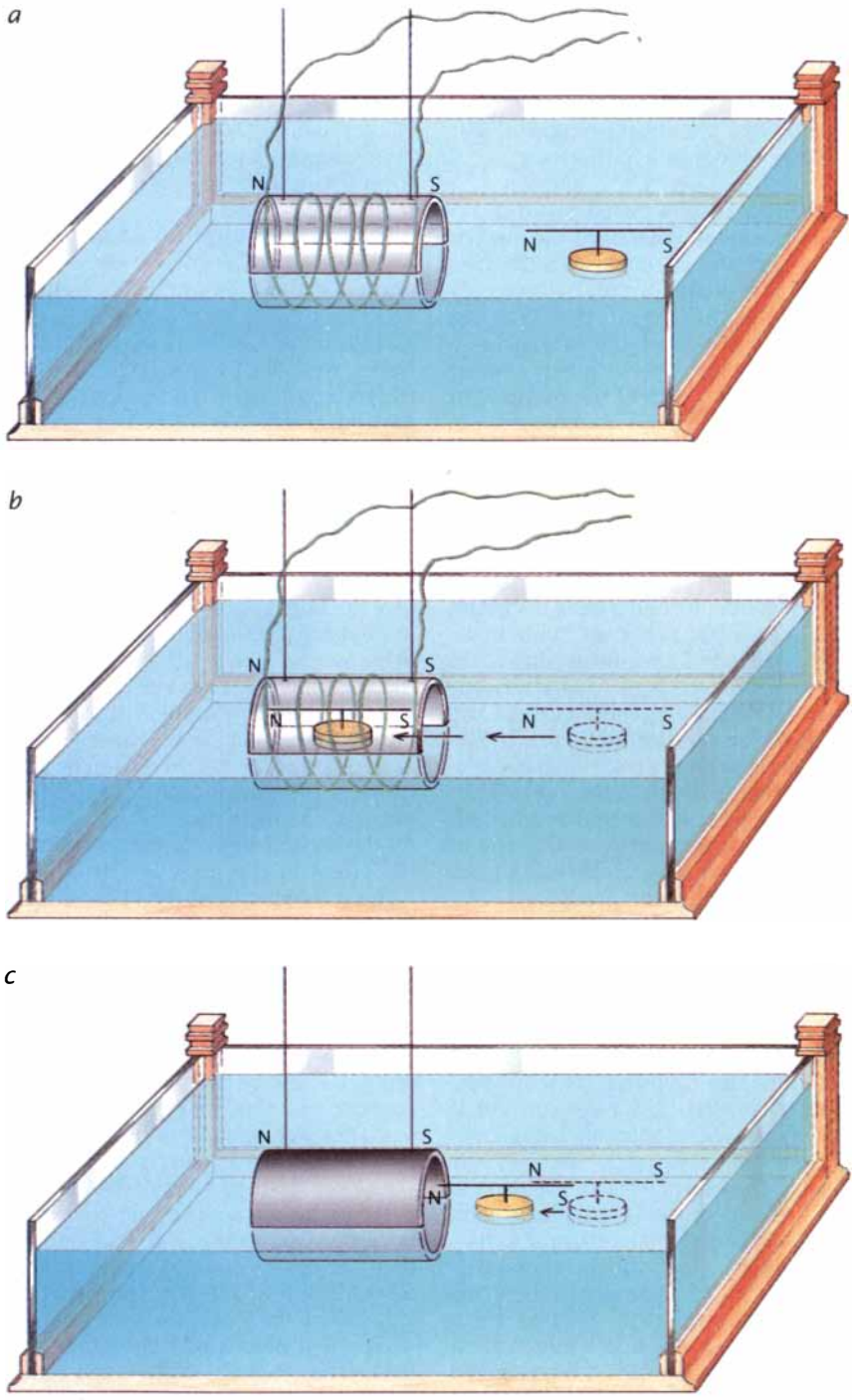
when he read his first report to the academy. No one paid much attention.

Between September 18 and September 25, the date of the academy's next meeting, Ampère applied his method. Having hypothesized a noumenal explanation—circular electric currents—for the phenomenon of magnetism, the next step was to test deductions based on the hypothesis: to show that circular electric currents produce the same effects as permanent magnets. He first tried to demonstrate the effect in copper wire that had been wound into helixes (coils shaped like springs). When he placed two helixes side by side and ran a current in the same direction through both of them at once [*see illustration on page 93*], he expected them to repel each other, like two magnets placed side by side with their north poles pointing in the same direction. Instead they attracted each other.

Ampère then tried a second approach. He wound his copper wire into flat spirals, with one end of the wire coming out of the center of the spiral and the other coming out of the spiral's edge. This time, when he turned on the current and held the spirals near each other, they did indeed act like magnets. On September 25 he demonstrated their various attractions and repulsions to his colleagues.

Why had helixes acted differently? The answer came from a chance observation. The wires leading to the two spirals were connected to the same battery, and so the wires connected to the same pole of the battery passed near each other. When Ampère turned on the current, he noticed that wires carrying current in the same direction attracted each other, even though they were not wound in circles. This interaction between straight wires, never before observed, gave Ampère the answer to the helix problem. Because his wires were uninsulated, he had wound his helixes very loosely, so that the individual coils in each helix were relatively far apart. The circular motion of the current had therefore been insignificant compared with its longitudinal travel from one end of the helix to the other. Hence the helixes had been much like two straight wires carrying current in the same direction, and so they had attracted each other.

To test this conclusion, Ampère wound a helix around a glass tube and passed the end of the wire back down the center of the tube. He expected the current passing down the center of the tube to cancel the longitudinal effect of the current flowing from one



APPARENT CONTRADICTION of Ampère's fundamental hypothesis of magnetism came from experiments done by Michael Faraday. Faraday wound a helix of insulated copper wire around a hollow glass tube and suspended the tube in a tank of water (*a*). He then attached a long, magnetized needle to a cork floating near the tube and ran a current through the helix. If the current-carrying helix were exactly like a magnet, he argued, the cork should float up to the tube until the needle was just inside the helix; then one magnetic pole of the needle would be as close as possible to the opposite pole of the helix-magnet. Instead (*b*) the cork floated all the way through the tube until both of the needle's poles were near the corresponding poles of the helix. In another experiment (*c*) Faraday rolled a sheet of steel into a tube, magnetized it and suspended it in the water. This time, as expected, the needle floated up to one end of the tube and stopped. Faraday argued that the current-carrying helix and the magnet were therefore not identical. (Ampère was able to reconcile this result with his hypothesis by pointing out that in the helix the needle had been in the center of the current and in the steel tube it had been outside all the small loops of current; one could therefore expect the needle to behave differently in the two situations.)

end of the helix to the other, allowing the effects of the current's circular component to become apparent. Helixes constructed in this way behaved exactly like permanent magnets, confirming Ampère's hypothesis.

These results raised one difficult question: Where are the electric currents in a permanent magnet? There are really only two possibilities. Either the currents flow in circles around the axis of the magnet as a whole or they flow in much smaller circles around each of the particles of which the magnet is composed. On Fresnel's suggestion, Ampère hypothesized that the currents flow around individual molecules of the magnet.

Such a hypothesis required experimental test; Ampère based his test on an experiment done by his friend Arago. Arago had wound a helix of copper wire, and at the center of the helix he had suspended an iron needle. When he connected the helix to a battery, the resulting circular electric current had magnetized the needle. Hence if Ampère's theory was correct, the circular current in the helix had created circular currents within the needle. But were the currents around the axis of the needle or around the individual molecules within the needle?

Ampère decided to answer this question by bending a thin ribbon of copper into a ring and suspending it within a cylindrical coil of insulated copper wire. The diameter of the ring was slightly smaller than that of the coil, and the ring and the coil were aligned so that they were concentric and their axes were parallel. If current in a helix had created circular currents around the axis of Arago's needle, Ampère reasoned, then a similar current should cause a circular current to flow around the copper ribbon, temporarily causing it to act as a magnet. He tested for such a current by holding a bar magnet up to the ring while current was flowing in the coil. If the ring had been magnetized, it would have been deflected by the bar magnet, but, as Ampère had expected, there was no deflection. Ampère cited this experiment publicly as weighty evidence for his molecular-current hypothesis.

Just at that time, however, his entire theory concerning the cause of permanent magnetism faced contradiction. In late 1821 an anonymous history of electromagnetism—written, it turns out, by the English physicist Michael Faraday—was published in England and translated immediately into French. The book outlined a pair of experiments designed to refute Ampère's central hypothesis that permanent magnetism is simply the result of circular electric currents. According to Faraday, the experimental results had shown that the magnetism of permanent magnets was distinctly different from the magnetism of current-carrying helixes.

In the first experiment a helix made of insulated copper wire was wound around a wide, hollow glass tube. A tank was filled with water and the glass tube was half-submerged in the water, with its long axis parallel to the water's surface. Then a long, magnetized needle was placed on a cork floating near the tube and an electric current was passed through the helix. If the helix were exactly like a magnet, Faraday argued, the cork should float up to the glass tube and then stop, because then one pole of the needle (say the north pole) would be as close as possible to the opposite pole of the helix-magnet (the south pole). Instead the cork floated up to one end of the tube and then proceeded through it (down the center of the helix), until both poles of the needle rested directly under the similar (not the opposite) poles of the helix-magnet.

The second experiment examined the effect in the case of a true permanent magnet. A sheet of steel was rolled up to form a hollow tube, magnetized, and suspended halfway in the water. This time the cork floated up to the hollow tube and stopped directly under the magnet's south pole, confirming, said Faraday, that current-carrying helixes are not the same as permanent magnets, and thus that permanent magnetism is not the result of circulating electric currents.

Ampère found a way out. If the currents in magnets circulate around the individual molecules, he reasoned, then the center of a steel tube *should* be qualitatively different from that of a helix. In the helix the magnetized needle had been enclosed within the circulating current; in the steel tube, on the other hand, the compass needle had been outside all the many molecular currents. Hence one could expect the needle to act differently in the two cases. Having given this explanation (which is essentially correct), Ampère was now publicly committed to the concept of molecular currents.

The strength of Ampère's commitment became apparent in the summer of 1822, when he repeated the experiment that involved a circle of copper ribbon and a copper coil. This time, however, he tested the ribbon with a powerful horseshoe magnet instead of a weaker bar magnet, and the ribbon actually was deflected. Ampère's reaction to this result is somewhat puzzling. The result seems to contradict his theory of molecular currents, but he did not respond by testing the theory further. He made only a passing mention of the experiment in his report to the academy that September, with the astonishing remark that the effect had no theoretical significance. In fact, Ampère had unwittingly observed the electromagnetic induction of one current by another, but it was not until 1832, after Faraday had discovered and investigated electromagnetic induction, that Ampère realized how narrowly he had missed an important discovery.

Ampère's basic concepts of electrodynamics never changed after 1822. What did change was his ability to quantify his theory. After he had formulated his theory of permanent magnetism, the next task was to determine experimentally how strong the various electromagnetic forces are. Ampère decided that the fundamental interaction in electrodynamics is the force acting between two current-carrying wires, and so he set about the difficult job of measuring that force. Once again, his ability to hypothesize aided him. Unlike gravitational forces, which can be treated mathematically as forces acting between simple geometric points, the forces due to a current along a wire cannot always be treated as simple local phenomena.

Ampère's idea was to consider infinitesimally small segments of the current-carrying wires and to assume that the forces acting between such segments varied as the inverse of the square of the distance between the segments. He then found the total force between the two wires by integrating—by mathematically adding up all the infinitesimal units of force, taking into account the directions in which the forces might act depending on how the wires were bent. Ampère originally considered the special case in which the two wires lie in the same plane. He later generalized his result to take account of wires lying in separate planes, no matter how the planes are angled in relation to each other. That generalization made it possible to consider wires twisted in any way whatever in three-dimensional space. His end result was a famous and compact formula by which one can calculate the electrodynamic force acting between two wires as long as one knows the strength of the currents and the geometric arrangement of the

wires. In 1826 Ampère reworked his earlier research papers to produce his definitive book, *Mémoire sur la théorie mathématique de phénomènes électrodynamiques uniquement déduite de l'expérience* (Theory of Electrodynamic Phenomena Deduced Uniquely from Experiment).

After 1827 Ampère's health began to decline rapidly. He abandoned creative scientific research and turned to his final work on the philosophy of science. Here he rediscovered some of the inspiration of his early youth. He was enraptured by Gottfried Wilhelm von Leibniz' doctrine of preestablished harmony, which held that Man's mind is a copy, albeit an imperfect one, of the mind of God. Since Man's reasoning process is an image of God's reasoning process, Leibniz said, and since God's reason created the universe, the human mind should be able to understand the universe through a process of pure reason—in other words, there should be a preexisting harmony between the laws of the universe and the reasoning powers of mankind.

Ampère decided that the correspondence between God's reason, human reason and the inherent rationality of the universe should make it possible to use what is essentially a process of taxonomy to find the ultimate Truth. If one could outline all the sciences the human mind could possibly construct, Ampère argued, one would have the basic key to all possible truth, since the mind is structured in a way that corresponds directly with the structure of the universe. It would remain only to fill in the contents of the cosmic taxonomic chart.

Ampère produced many of these charts, intended to be tools of fundamental research, before he died, probably of pneumonia, in 1836. And so Ampère ended almost as he had begun: as an encyclopedist committed to the unity of all knowledge, for all knowledge is but the reflection of the unity of the divine mind.

FURTHER READING

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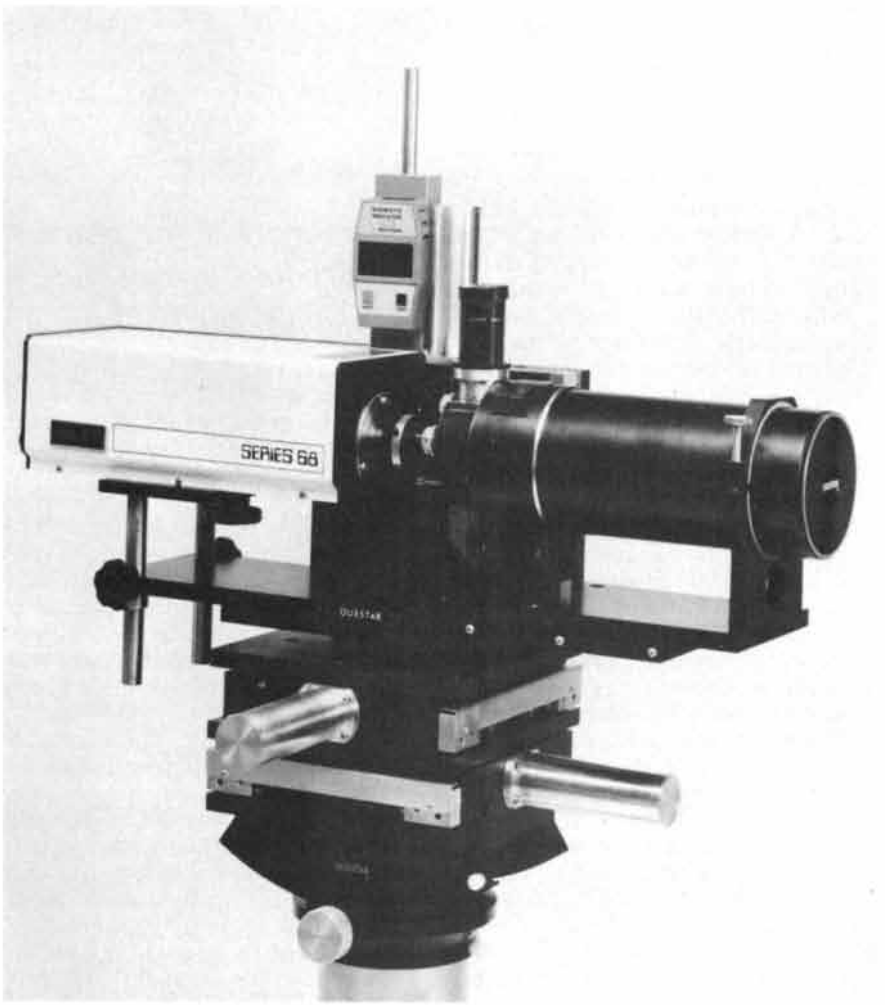
A Questar® System for the Laboratory



In the laboratory this Questar visible-data imaging system is an indispensable tool capable of remote non-contact gauging and alignment to .0001 precision. It is a matched photo-visual system, with translation stages that position in 3 axes, with a digital indicator calibrated in ten thousandths. This is basically the resolution of the QM 1 which is the heart of the system. One of the unique features of the QM 1 is a variable focal length over a working range of 22 to 66 inches, covering fields of view from 1 to 32 mm. The equipment, shown above, is mounted on a specially designed, highly stable floor stand with rising centerpost and is easily portable.

This is no single-purpose system, but a remarkable Jack-of-all-trades that is used in projects as varied as crack propagation analysis, documentation of crystal growth, measurement of thermal expansion of a part in real time, or whatever difficult problem of measurement, imaging and recording has a need of solution. So why not start thinking about all the ways you can put this self-contained little laboratory to work, not only on your present project but in special applications on down the road.

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